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6 UNCERTAINTY ANALYSIS

Uncertainty analysis, as it pertains to the SFWMM, refers to the establishment of confidence limits or uncertainty bands for model output variables as a function of the assumed confidence limits for the model input parameters. Model uncertainty analysis provides information to the modeler and decision-maker about the limitations of the model output. By being aware of the uncertainties associated with model output, misuse of performance measures derived from such output can be reduced. Also, similar to sensitivity analysis, future efforts on data collection of the model is limited by the uncertainties in the output. This chapter summarizes the methods used and the findings of the certainty/uncertainty analysis for the SFWMM. The method used in this chapter is based on Trimble (1995a).

6.1 METHODOLOGY

Model output uncertainty is a function of three major uncertainties: model input data uncertainty, model algorithm uncertainty, and model input parameter uncertainty. This chapter focuses on the last source of model output uncertainty: model input parameter uncertainty. The approach is two-fold:

1. Model output uncertainty is estimated as a function of parameter uncertainty using a first-order approximation
2. Total output uncertainty is determined by applying a regression analysis technique

6.1.1 Uncertainty band using first-order approximation

The first-order approximation of uncertainty associated with model output or performance measure is derived by obtaining the variance of the first-order approximation of the multivariable Taylor series expansion of the model output or an associated performance measure. Assuming an independent set of parameters, the variance can be expressed as:

$$VAR[M] = \sum_i \left[\left(\frac{\partial M}{\partial P_i} \right)^2 VAR(P_i) \right] \quad (6.1.1.1)$$

for $i = 1, 2, \dots, n$; where:

- M = output variable or performance measure
 $VAR[M]$ = variance of output variable or performance measure
 P_i = parameter i
 $VAR(P_i)$ = variance of parameter i
 $\partial M / \partial P_i$ = sensitivity coefficient, or partial derivative of M at the mean value of input parameter i
 n = number of parameters

This equation shows that the output uncertainty due to parameter uncertainty can be estimated by multiplying the variance of each parameter by the square of the parameter's sensitivity coefficient and summing the values for all parameters. This method allows for estimation of percentage contribution of each parameter to the total output variance.

Calculations associated with coefficients of parameter sensitivity are presented in Chapter 5. The correlation matrix (Table 5.2.3) shows only minor correlation among the parameters. Therefore, the assumption of independent parameters is valid. By assuming each model input parameter as a normally distributed random variable, the variance of parameter i can be approximated by the following equation (Loucks and Stedinger, 1994):

$$VAR(P_i) = [(P_{95} - P_{05})/3.3]^2$$

where:

- P_{95} = upper limit of the 90% confidence interval
- P_{05} = lower limit of the 90% confidence interval

When the likelihood of each parameter value is represented by a normal distribution, the distance between the parameter mean value and the upper or lower limit of the 90% confidence band is 1.645 times the standard deviation. The upper limit is used hereafter in the calculation of the uncertainty band. The upper limit value is obtained from the results of the sensitivity analysis in Chapter 5, which are: 10% increase for WPET, 20% increase for CPET, and 50% increase for all the other parameters.

6.1.2 Regression analysis

In order to express total uncertainty of the model output, i.e., the combined effects of all three sources of uncertainties: model input data uncertainty, model algorithm uncertainty, and model input parameter uncertainty; a linear regression analysis is applied with observed data as independent variable and simulated data as dependent variable. The linear regression analysis provides an initial quantitative evaluation of the model accuracy. Since it combines all the error from all sources together, and these errors might compensate for each other, no direct comparison could be made between the uncertainty band from regression analysis and the first-order parameter analysis without further studying the nature of the sources of error and their weight in the regression uncertainty band. It would be helpful to have an overview of the uncertainty along with the uncertainty analysis caused by input parameters.

Uncertainty bands for an individual predicted value can be estimated using the following relationship (Lal, 1994; Walpole and Myers, 1990):

$$Y = a + bx \pm s_e [1 + 1/n + (x - \bar{x})^2 / SS_{xx}]^{0.5} t_{0.95} \quad (6.1.2.1)$$

where:

- Y = model simulation value to be predicted using the regression equation;
- a = regression coefficient representing the Y-intercept of the regression line;
- $a = (\sum X_{sim} - b \sum X_{obs}) / N$
- b = regression coefficient representing the slope of the regression line;
- $b = \frac{N \sum (X_{sim} X_{obs}) - \sum X_{sim} \sum X_{obs}}{N \sum (X_{obs})^2 - (\sum X_{sim})^2}$
- x = observed value;

- \bar{x} = mean of the observed value;
 $SS_{xx} = \sum_{i=1}^n (x_i - \bar{x})^2$, where x_i is the individual observed value;
 $t_{0.95}$ = student-t value for a one-tail 95% confidence interval; and
 s_e = square root of the unbiased estimate of the standard error of the regression equation.

The estimator s_e^2 is equal to the sum of the squares of the errors about the regression line divided by the number of degrees of freedom which, in turn, is equal to the number of points used in the regression minus two.

6.2 RESULTS

The model output variable is presented by the half-width of the 90% uncertainty band. The terms uncertainty band and certainty band are used interchangeably in the discussion. The general rule is the narrower the bands, the greater the level of certainty. Tables 6.2.2 through 6.2.8 contain results for the first-order approximation uncertainty analysis for each region (BCNP, WCAs, ENP, LEC SA1, LEC SA2, LEC SA3, and Canals).

Some general statements (summarized in Table 6.2.1) can be made about the uncertainty band and contribution of each parameter for the modeling regions:

1. The average value of the half-width for all gages in BCNP is around 0.73ft. WPET and SEEP have the strongest contribution in this area.
2. The average value of the half-width for all gages in ENP is around 0.39ft. WPET, MAN and SEEP have relatively stronger contribution among all the parameters.
3. LEC SA1 has an average uncertainty band of around 0.73ft. GWHC, CHHC and CPET have stronger contributions in this region.
4. LEC SA2 has an average uncertainty band of 0.48ft. CHHC, SEEP and CPET have stronger contributions in this region.
5. LEC SA3 has an average uncertainty band of 0.35ft. CPET, SEEP and WPET have stronger contributions in this region.
6. For the WCAs, the average uncertainty band is 0.40ft. WPET, GWHC, SEEP and MAN have stronger contributions among all the parameters.
7. For canals, the average uncertainty band is 0.34ft. WPET, CPET and SEEP have stronger contributions to the uncertainty in this area.

Table 6.2.1 Average uncertainty band values per region, and parameters that contributed the most, based on first-order approximation

Region	Average uncertainty band value (ft)	Parameters that contributed the most to the uncertainty in the region
BCNP	0.73	WPET, SEEP
ENP	0.39	WPET, MAN, SEEP
LEC SA1	0.73	GWHC, CHHC, CPET
LEC SA2	0.48	CHHC, SEEP, CPET
LEC SA3	0.35	CPET, SEEP, WPET
WCAs	0.40	WPET, GWHC, SEEP, MAN
Canals	0.34	WPET, CPET, SEEP

Table 6.2.2 Half-Width of 90% Uncertainty Band and Contributions by Parameters for BCNP

Station	Band	Percentages of Contribution by Parameter							
		WPET	GWHC	CHHC	DET	SEEP	MAN	CPET	STOC
BCNP10	0.34	56	13	3	1	17	0	7	4
BCNP12	0.45	58	4	5	2	18	0	12	0
BCNP13	0.23	32	3	7	7	26	1	17	6
BCNPA2	1.13	36	9	8	5	22	4	14	3
BCNPA5	0.35	77	9	1	0	8	0	3	1
BCNPA8	2.05	15	8	3	7	30	11	19	7
BEARI	1.22	28	2	28	4	19	4	12	3
C296	0.65	45	2	6	6	22	0	14	4
C54	0.3	28	16	0	4	12	17	9	13
L28.GA	0.46	1	5	6	7	26	23	17	16
LOOP1	0.74	46	8	5	5	22	1	12	2
LOOP2	0.49	67	8	2	3	12	0	7	1
MONRD	1.45	34	8	6	6	24	3	15	4
OKA858	0.62	17	30	37	2	7	2	5	1
ROBLK	0.47	58	7	4	4	17	0	9	1
TAMI40	0.51	59	7	4	4	17	0	10	0
TAMIAM	0.95	8	8	4	9	31	13	20	9

Table 6.2.3 Half-Width of 90% Uncertainty Band and Contributions by Parameters for ENP

Station	Band	Percentages of Contribution by Parameter							
		WPET	GWHC	CHHC	DET	SEEP	MAN	CPET	STOC
EP12R	0.4	41	11	5	4	12	1	24	2
EP9R	0.17	9	3	0	4	22	57	1	4
EPSW	0.54	39	8	9	5	14	0	20	5
G1502	0.41	0	4	10	10	23	22	16	15
G3272	0.85	10	1	10	9	28	9	20	13
G3273	0.44	0	2	11	10	24	21	17	14
G3437	0.49	45	15	3	3	22	0	13	1
G3576	0.19	1	0	4	3	4	82	3	3
G3578	0.37	6	2	8	7	20	37	13	7
G620	0.25	9	3	3	4	8	57	6	11
L67ES	0.23	73	16	0	0	1	10	0	0
L67EXE	0.21	2	0	9	8	20	38	15	9
L67EXW	0.2	1	0	2	2	8	77	6	4
NESRS1	0.22	0	0	9	8	21	38	15	8
NESRS2	0.23	5	2	8	9	21	31	12	12
NESRS3	0.23	55	17	2	4	1	16	0	4
NESRS4	0.58	15	5	5	5	21	29	14	5
NESRS5	0.53	8	3	9	8	28	19	18	7
NP-201	0.26	57	3	4	3	17	7	9	1
NP-202	0.19	4	0	2	2	7	76	6	3
NP-203	0.2	4	0	4	3	11	68	8	2
NP-205	0.26	36	0	3	4	8	27	7	15
NP-206	0.64	2	0	8	9	28	19	18	15
NP-207	0.71	57	2	4	4	18	2	12	2
NP-33	0.49	7	3	7	7	27	25	18	7
NP-34	0.3	55	1	1	2	3	28	3	7
NP-35	0.17	15	5	6	7	28	11	20	9
NP-36	0.25	1	1	6	6	19	48	14	6
NP-38	0.23	81	1	1	1	4	10	2	0
NP-44	0.32	51	0	1	4	7	15	4	18
NP-46	0.92	50	3	5	4	20	3	13	2
NP-62	0.22	31	0	2	4	6	44	4	10
NP-67	0.57	53	4	4	4	18	1	13	2
NP-72	0.35	88	2	0	0	0	1	0	7
NP-TSB	0.81	38	9	6	4	21	3	17	2
RUTZKE	0.6	12	3	10	9	21	16	19	10

Table 6.2.4 Half-Width of 90% Uncertainty Band and Contributions by Parameters for LEC SA1

Station	Band	Percentages of Contribution by Parameter							
		WPET	GWHC	CHHC	DET	SEEP	MAN	CPET	STOC
G1213	0.45	0	84	8	0	0	0	7	0
G1260	0.57	3	60	20	1	4	1	4	7
G1315	0.57	1	91	0	0	1	0	5	2
G2030	0.49	10	44	16	4	17	5	0	4
PB1495	0.47	8	4	51	3	8	3	20	2
PB1515	0.75	6	53	7	2	6	1	24	0
PB1661	1.53	9	23	9	12	9	12	14	12
PB445	0.33	0	21	35	11	0	11	14	8
PB561	0.37	6	2	71	3	11	3	0	5
PB683	1.39	19	7	4	5	35	5	20	5
PB732	0.24	1	1	17	0	1	0	69	11
PB809	0.87	24	5	10	7	29	7	11	7
PB88	0.68	25	5	1	9	32	7	12	8
PB900	0.59	3	36	13	13	9	13	1	12
PB99	0.59	2	12	74	0	2	1	8	1
WPBCA	0.99	5	5	17	0	58	0	16	0
PB831	0.28	50	1	9	3	2	8	2	25
PB565	2.5	16	16	1	16	16	4	15	17
PB109	0.91	13	14	10	22	0	10	6	25
JUP.W	0.41	1	23	7	2	0	0	59	9
LOXR1	0.39	3	1	3	52	1	1	37	4
SCUM	0.76	12	0	3	4	2	0	78	1

Table 6.2.5 Half-Width of 90% Uncertainty Band and Contributions by Parameters for LEC SA2

Station	Band	Percentages of Contribution by Parameter							
		WPET	GWHC	CHHC	DET	SEEP	MAN	CPET	STOC
F291	0.19	4	0	72	1	1	1	21	0
G1215	0.58	3	43	21	1	4	1	26	1
G1220	0.5	13	0	47	4	14	4	15	3
G1221	0.11	3	16	54	3	14	2	5	4
G1222	0.37	33	1	8	2	2	2	51	1
G1223	0.18	0	0	73	1	5	1	18	2
G1224	0.23	11	2	46	5	25	5	1	6
G1225	0.18	2	0	66	2	12	2	12	4
G1316	0.25	11	6	38	2	4	2	36	0
G1472	0.3	14	2	38	3	11	3	26	3
G1473	0.19	14	9	28	6	29	6	0	7
G1636	0.72	23	1	13	6	20	7	21	8
G1637	0.48	5	14	0	9	48	9	8	7
G2031	0.41	13	5	45	3	9	2	22	1
G2032	0.38	18	21	8	8	26	8	3	9
G2033	0.17	12	15	0	9	28	9	0	28
G2034	0.46	34	1	9	3	4	2	44	2
G2035	0.91	22	0	10	6	23	6	26	6
G2147	0.51	24	7	3	7	30	7	9	13
G2275	0.22	10	20	32	3	14	3	2	16
G2376	0.49	34	2	56	1	2	1	4	1
G2443	0.63	20	1	22	7	29	7	7	8
G2444	0.89	4	59	23	2	7	2	0	3
G561	0.36	7	0	69	2	7	2	12	1
G616	0.29	0	0	67	0	0	0	30	2
G617	0.21	3	11	23	1	21	2	36	4
G820A	0.75	15	13	18	5	18	5	24	2
G970	0.3	22	1	24	4	9	6	25	9
S329	2.67	23	7	5	7	29	7	14	9

Table 6.2.6 Half-Width of 90% Uncertainty Band and Contributions by Parameters for LEC SA3

Station	Band	Percentages of Contribution by Parameter							
		WPET	GWHC	CHHC	DET	SEEP	MAN	CPET	STOC
EVER1	0.52	51	4	4	3	11	2	21	3
EVER2B	0.47	52	6	9	2	6	1	23	1
EVER3	0.18	26	6	0	5	30	21	3	10
EVER4	0.19	23	1	1	7	25	27	0	16
F179	0.49	20	11	16	5	18	5	22	3
F319	0.23	6	1	4	10	39	7	0	33
F358	0.27	25	4	11	1	1	0	57	0
F45	0.22	6	58	12	1	3	1	18	0
FROGP	0.22	36	19	10	2	14	4	7	7
G1166	0.12	6	16	63	0	2	1	12	0
G1183	0.23	20	1	23	2	5	1	47	0
G1251	0.4	62	5	3	3	12	0	14	0
G1362	0.28	6	0	0	10	48	13	0	22
G1363	0.41	11	8	1	9	41	11	5	14
G1486	0.19	4	1	10	2	19	4	42	19
G1487	0.74	31	10	8	4	17	3	23	3
G1488	0.7	65	13	6	1	3	2	10	0
G3074	0.75	24	25	9	3	10	3	24	1
G3327	0.09	4	0	56	2	7	1	18	12
G3328	0.2	23	6	28	3	10	3	28	0
G3329	0.2	0	6	21	8	35	6	0	22
G3353	0.19	68	3	0	2	2	18	0	5
G3354	0.43	46	10	11	2	7	0	22	1
G3439	0.28	0	33	4	8	30	9	0	16
G553	0.71	25	10	4	5	18	5	33	1
G580A	0.16	4	11	9	2	8	1	30	34
G596	0.45	4	1	18	10	17	18	18	14
G613	0.27	0	5	0	10	52	18	0	14
G614	0.55	15	4	1	9	42	10	5	14
G757A	0.2	0	0	1	10	57	13	0	19
G789	0.22	40	14	14	0	5	1	22	4
G852	0.11	9	7	42	2	9	2	29	0
G855	0.18	24	0	6	1	5	2	51	12
G858	0.38	26	5	10	2	8	2	46	0
G860	0.35	24	21	1	3	12	4	35	0
G864	0.22	31	2	13	0	1	1	50	2
G973	0.29	7	17	4	9	38	7	5	12
G975	0.96	1	2	4	11	44	9	15	13
G976	0.6	0	31	1	9	35	6	5	11
S18	0.18	23	13	6	7	30	7	4	10
S182	0.43	23	5	12	5	19	5	29	2
S196A	0.31	5	0	1	10	53	12	0	19

Table 6.2.7 Half-Width of 90% Uncertainty Band and Contributions by Parameters for WCAs

Station	Band	Percentages of Contribution by Parameter							
		WPET	GWHC	CHHC	DET	SEEP	MAN	CPET	STOC
G618	0.18	18	0	1	7	15	37	8	13
L28-2	0.66	43	10	4	4	24	0	12	3
L29	0.44	47	8	7	4	20	0	13	2
SHARK	0.4	86	6	6	0	1	0	1	0
WCA2E4	0.26	25	44	0	1	2	29	0	0
WCA2F1	0.62	33	20	5	4	23	0	11	4
WCA2F4	0.26	26	45	0	1	2	27	0	0
WCA2U1	0.29	0	20	5	9	11	32	16	6
1-7	0.42	57	22	2	1	5	0	9	3
1-8T	0.36	2	3	6	9	40	24	10	7
1-8C	0.26	17	15	5	6	28	23	4	3
2A-17	0.3	51	18	2	2	16	2	7	2
2A-300	0.45	44	17	4	3	19	0	9	4
2B-Y	0.66	10	31	2	0	56	0	0	0
1-9	0.63	5	40	1	1	51	2	0	0
3A-10	0.22	0	0	4	5	11	64	11	5
3A-11	1.37	27	8	6	6	27	2	16	7
3A-12	0.19	53	13	0	0	2	31	0	0
3A-2	0.3	50	9	3	3	16	10	7	2
3A-28	0.45	52	10	7	6	2	5	15	2
3A-3	0.36	71	9	2	3	0	9	5	1
3A-4	0.67	66	17	1	1	13	0	2	2
3A-9	0.47	49	12	4	3	21	0	8	3
3A-NE	0.3	67	8	1	1	10	10	3	1
3A-NW	0.17	46	5	1	1	6	39	2	0
3A-S	0.38	57	14	2	2	17	1	5	2
3A-SW	0.34	76	13	0	0	8	3	0	0
3B-2	0.23	24	6	4	7	26	19	7	7
3B-29	0.22	51	1	23	2	10	8	0	4
3B-3	0.2	28	1	4	5	17	39	3	4
3B-SE	0.43	16	0	0	12	38	8	12	13
G618	0.18	18	0	1	7	15	37	8	13
L28-2	0.66	43	10	4	4	24	0	12	3
L29	0.44	47	8	7	4	20	0	13	2
SHARK	0.4	86	6	6	0	1	0	1	0
WCA2E4	0.26	25	44	0	1	2	29	0	0
WCA2F1	0.62	33	20	5	4	23	0	11	4
WCA2F4	0.26	26	45	0	1	2	27	0	0

Table 6.2.7 (cont.) Half-Width of 90% Uncertainty Band and Contributions by Parameters for WCAs

Station	Band	Percentages of Contribution by Parameter							
		WPET	GWHC	CHHC	DET	SEEP	MAN	CPET	STOC
WCA2U1	0.29	0	20	5	9	11	32	16	6
1-7	0.42	57	22	2	1	5	0	9	3
1-8T	0.36	2	3	6	9	40	24	10	7
1-8C	0.26	17	15	5	6	28	23	4	3
2A-17	0.3	51	18	2	2	16	2	7	2
2A-300	0.45	44	17	4	3	19	0	9	4
2B-Y	0.66	10	31	2	0	56	0	0	0
1-9	0.63	5	40	1	1	51	2	0	0
3A-10	0.22	0	0	4	5	11	64	11	5
3A-11	1.37	27	8	6	6	27	2	16	7
3A-12	0.19	53	13	0	0	2	31	0	0
3A-2	0.3	50	9	3	3	16	10	7	2
3A-28	0.45	52	10	7	6	2	5	15	2
3A-3	0.36	71	9	2	3	0	9	5	1
3A-4	0.67	66	17	1	1	13	0	2	2
3A-9	0.47	49	12	4	3	21	0	8	3
3A-NE	0.3	67	8	1	1	10	10	3	1
3A-NW	0.17	46	5	1	1	6	39	2	0
3A-S	0.38	57	14	2	2	17	1	5	2
3A-SW	0.34	76	13	0	0	8	3	0	0
3B-2	0.23	24	6	4	7	26	19	7	7
3B-29	0.22	51	1	23	2	10	8	0	4
3B-3	0.2	28	1	4	5	17	39	3	4
3B-SE	0.43	16	0	0	12	38	8	12	13

Table 6.2.8 Half-Width of 90% Uncertainty Band and Contributions by Parameters for Canals

Station	Band	Percentages of Contribution by Parameter							
		WPET	GWHC	CHHC	DET	SEEP	MAN	CPET	STOC
S9HW	0.67	50	0	0	5	0	4	39	2
S334HW	0.58	41	9	7	4	20	1	14	4
S197HW	0.6	38	10	11	4	11	0	22	5
S340HW	0.72	44	13	2	2	19	0	6	13
S119HW	0.53	26	8	1	4	16	5	39	2
S11AHW	0.89	21	12	1	1	9	1	4	51
S44HW	0.31	22	7	5	7	25	7	19	9
E3HW	0.32	20	6	14	6	25	6	19	2
S22HW	0.46	45	1	5	3	10	4	25	7
G124HW	0.25	25	6	6	6	25	6	25	0
S13HW	0.25	18	4	4	5	17	5	15	32
S20FHW	0.28	31	2	7	3	12	3	37	6
S21HW	0.24	20	9	3	3	14	4	23	24
S123HW	0.29	25	17	0	2	9	3	40	3
S25HW	0.21	29	8	5	4	18	5	28	3
S36HW	0.18	25	4	9	5	20	5	21	10
S28HW	0.13	20	7	7	6	23	6	24	7
S331HW	0.21	41	6	15	1	0	1	30	5
S118HW	0.22	26	2	0	1	4	2	59	6
S27HW	0.06	27	4	4	4	16	4	27	14
G57HW	0.2	1	4	8	0	1	0	4	83
S155HW	0.65	11	10	11	10	11	10	11	24
S335HW	0.59	69	12	12	0	0	1	6	0
S37AHW	0.05	1	0	1	1	8	1	2	86
S33HW	0.04	2	29	1	2	11	2	53	0
S179HW	0.22	8	0	2	0	3	1	35	51
G56HW	0.09	6	1	0	4	11	3	0	75
S29HW	0.06	4	6	10	8	0	9	34	30
S18CHW	0.15	44	8	5	1	11	11	13	6
S339HW	0.3	10	3	0	0	0	21	0	66
S333HW	0.8	76	17	0	0	7	0	0	0
1-8C	0.43	54	38	3	0	4	0	1	0
S37BHW	0.1	18	6	6	6	42	7	7	9
S21AHW	0.08	8	4	9	12	53	13	0	1
S148HW	0.11	1	6	0	8	36	8	39	1
S165HW	0.17	3	7	3	3	25	5	13	41
S149HW	0.12	7	1	22	9	38	9	0	13
S177HW	0.18	20	10	2	5	45	7	3	8

Table 6.2.8 (cont.) Half-Width of 90% Uncertainty Band and Contributions by Parameters for Canals

Station	Band	Percentages of Contribution by Parameter							
		WPET	GWHC	CHHC	DET	SEEP	MAN	CPET	STOC
S176HW	0.19	4	1	2	4	32	6	0	52
S332HW	0.27	27	50	0	3	10	8	0	2
S167HW	0.17	4	6	0	4	37	6	15	28
G211HW	0.34	0	1	1	3	21	10	2	63
S26HW	0.29	5	3	5	3	13	3	5	61
C2.74	0.43	7	22	3	3	9	0	0	56
S30HW	0.3	10	0	0	8	50	9	0	23
G54HW	0.61	10	4	2	4	15	3	7	56
S166HW	0.51	12	2	3	7	35	8	1	31
S46HW	0.79	12	5	6	7	24	15	7	25
S344HW	0.91	4	0	7	7	17	17	18	31

For the linear regression analysis, the simulated daily stage data are plotted against observed data, as shown in Figure 6.2.1 and Figure 6.2.2 as examples. Equation 6.1.2.1 gives the uncertainty band for each individual predicted value. Seen from the equation, the further away the individual is from the mean, the larger the uncertainty would be. The larger the sample size is, the smaller the difference among individual predictions would be. Daily stage data were applied for the regression analysis. The sample size for most of the gages is large enough to omit the difference in uncertainty band between different measurements. To get an overview of the uncertainty for the complete time series, the mean of regression values were used to get the 90% confidence interval.

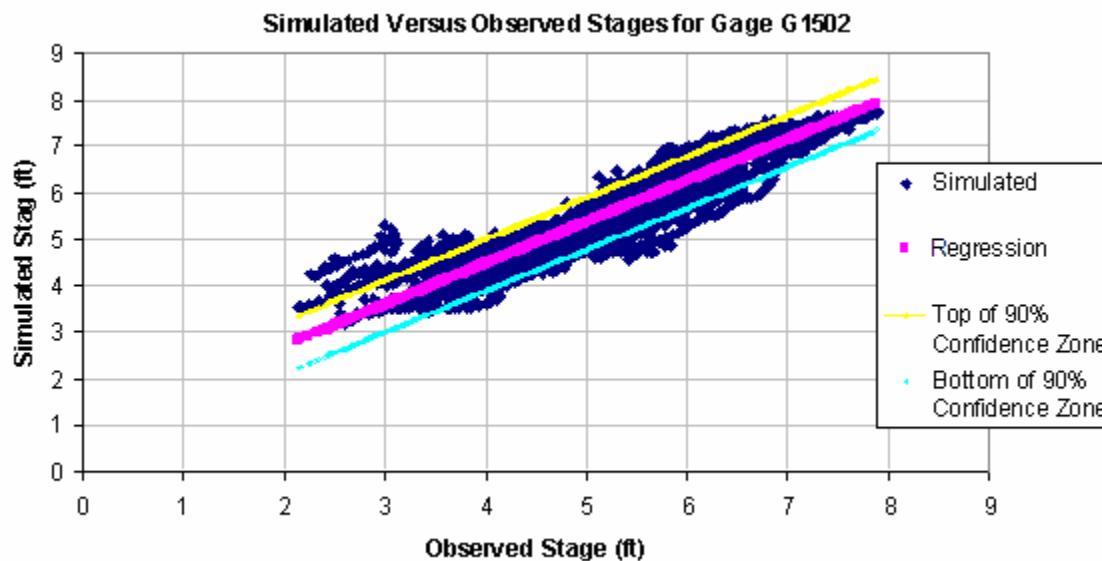


Figure 6.2.1 Simulated Versus Observed Stages for Gage G1502 in ENP

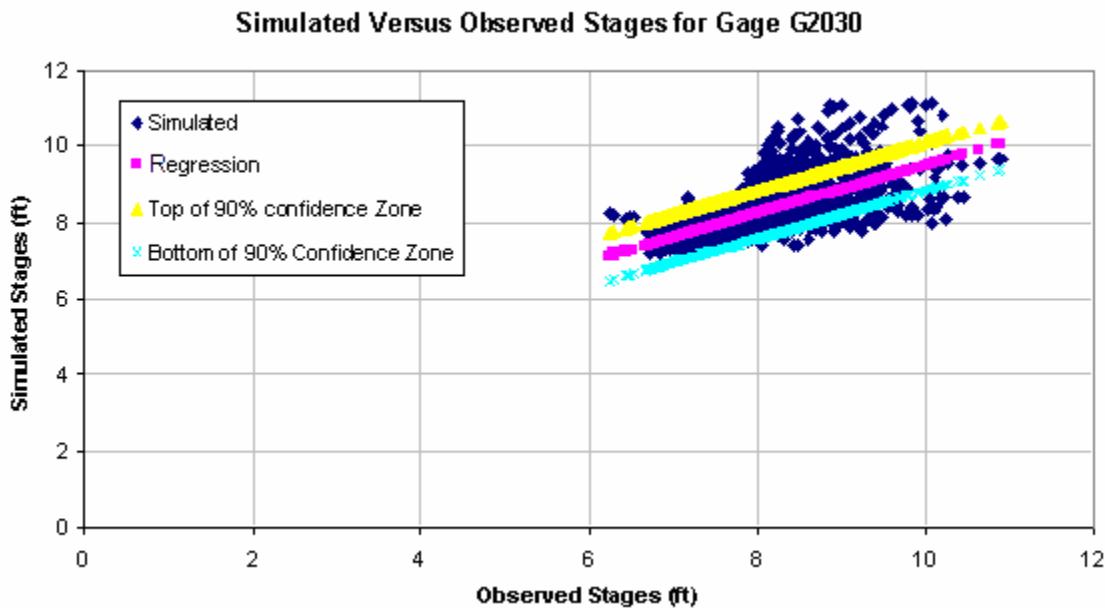


Figure 6.2.2 Simulated Versus Observed Stages for Gage G2030 in ENP

The deviation of the regression line from the unity line is a measure of model bias. The scatter of data about the regression line is a measure of the model algorithm, the associated input data, and the corresponding parameters.

The results of the uncertainty analysis using regression analysis are shown in Table 6.2.9 to Table 6.2.15 for all of the regions. The following general conclusions can be made about these tables:

1. The average uncertainty band for all the regions is larger than the uncertainty band presented using parameter uncertainty alone, but this is not always so for individual gages.
2. The slope of the linear regression lines (b) are not always close to unity, which shows that the simulated stages of these gages are biased.
3. The average uncertainty band for BCNP is about 0.76ft.
4. The average uncertainty band for ENP is around 0.44ft.
5. The average uncertainty band for LEC SA1 is around 0.79ft.
6. The average uncertainty band for LEC SA2 is around 0.69ft.
7. The average uncertainty band for LEC SA3 is around 0.52ft.
8. The average uncertainty band for WCAs is around 0.49ft.
9. The average uncertainty band for Canals is around 0.54ft.

Table 6.2.9 Half-Width of 90% Total Uncertainty Band for BCNP

Station	Sample Size	a (intercept)	b (slope)	Uncertainty Band
BCNP10	1327	1.70	0.60	0.36
BCNP12	1461	7.16	0.49	0.70
BCNP13	96	3.58	0.72	0.29
BCNPA2	1817	1.98	0.83	1.07
BCNPA5	1773	-1.63	1.15	0.22
BCNPA8	1798	1.03	1.04	2.21
BEARI	1823	0.89	0.91	1.06
C54	4378	3.92	0.65	0.66
L28.GA	4323	2.43	0.81	0.54
LOOP1	3782	-0.29	1.00	0.63
LOOP2	3857	0.27	0.93	0.33
MONRD	1774	-2.33	1.16	1.40
OKA858	1503	2.23	0.87	0.41
ROBLK	1830	0.39	0.89	0.36
TAMI40	4373	1.62	0.76	0.62
TAMIAM	4325	1.67	0.63	1.32

Table 6.2.10 Half-Width of 90% Total Uncertainty Band for ENP

Station	Sample Size	a (intercept)	b (slope)	Uncertainty Band
EP12R	2495	0.09	0.81	0.33
EP9R	2223	0.08	0.98	0.13
EPSW	3497	-0.50	1.20	0.48
G1502	4352	0.90	0.89	0.56
G3273	4310	0.84	0.90	0.59
G3437	3288	1.52	0.67	0.79
G3576	297	2.14	0.71	0.23
G3578	259	2.46	0.68	0.45
G620	3899	-0.81	1.15	0.29
L67ES	1887	0.41	0.93	0.11
L67EXE	4097	1.12	0.85	0.32
L67EXW	4194	2.03	0.71	0.56
NESRS1	4205	1.32	0.82	0.33
NESRS2	3872	0.19	0.99	0.28
NESRS3	3660	0.51	0.94	0.22
NESRS4	1054	-1.29	1.22	0.42
NESRS5	3118	1.76	0.78	0.64
NP-201	3831	0.34	0.94	0.22
NP-202	4002	0.47	0.94	0.15
NP-203	3780	0.41	0.94	0.17
NP-205	4275	0.76	0.89	0.29
NP-206	3737	1.27	0.82	0.85
NP-207	4286	-0.34	1.03	0.58
NP-33	4190	0.60	0.94	0.52
NP-34	4109	-0.02	1.04	0.15
NP-35	4252	0.31	0.87	0.24
NP-36	4138	0.47	0.91	0.26
NP-38	4092	-0.08	1.03	0.09
NP-44	4116	0.99	0.70	0.87
NP-46	3717	-0.37	0.97	0.80
NP-62	3488	0.75	0.69	0.61
NP-67	3964	-0.08	0.92	0.15
NP-72	3812	0.55	0.77	0.60
NP-TSB	4383	1.05	0.54	1.23
RUTZKE	542	1.34	0.81	0.76

Table 6.2.11 Half-Width of 90% Total Uncertainty Band for LEC SA1

Station	Sample Size	a (intercept)	b (slope)	Uncertainty Band
G1213	4378	2.39	0.80	0.42
G1260	4380	1.08	0.71	1.03
G1315	4303	1.53	0.85	0.40
G2030	2036	3.17	0.63	0.63
JUP.W	163	0.59	0.72	0.68
LOXR1	1435	2.45	0.74	0.42
PB109	2775	12.06	0.35	1.59
PB1495	2933	0.65	0.78	0.46
PB1515	611	-0.30	1.01	0.35
PB445	4340	6.85	0.58	0.42
PB561	4326	6.19	0.58	1.31
PB565	4283	2.52	0.49	2.46
PB683	4279	8.66	0.43	1.70
PB732	4253	0.09	0.98	0.05
PB809	4305	0.15	1.03	0.93
PB831	4219	0.58	0.97	0.10
PB88	3146	2.38	0.56	1.31
PB900	4271	3.93	0.74	0.42
PB99	4320	-0.25	1.02	0.18
SCUM	93	2.57	0.66	0.96

Table 6.2.12 Half-Width of 90% Total Uncertainty Band for LEC SA2

Station	Sample Size	a (intercept)	b (slope)	Uncertainty Band
G1215	4219	1.44	0.56	1.97
G1220	4336	0.07	0.87	0.42
G1221	4308	1.40	0.40	0.81
G1222	2678	1.39	0.60	0.60
G1223	4349	-0.10	1.05	0.08
G1224	4296	-0.26	1.21	0.34
G1225	4322	0.44	0.84	0.27
G1316	4191	1.98	0.74	0.35
G1472	3529	0.06	0.90	0.27
G1636	4293	0.45	0.74	0.69
G1637	4219	1.89	0.61	0.78
G2031	4350	1.60	0.77	0.38
G2032	4320	1.88	0.63	0.61
G2033	4306	2.31	0.67	0.45
G2034	4291	0.92	0.71	0.47
G2035	4308	-0.81	1.22	0.93
G2147	4296	1.61	0.56	1.28
G2376	4092	2.11	0.65	0.48
G2443	2895	2.24	0.68	0.76
G2444	2789	0.16	1.03	0.46
G616	3618	2.94	0.65	0.73
G617	4383	1.04	0.74	0.27
G970	4161	0.21	0.89	0.21
S329	4266	1.98	0.66	2.91

Table 6.2.13 Half-Width of 90% Total Uncertainty Band for LEC SA3

Station	Sample Size	a (intercept)	b (slope)	Uncertainty Band
EVER1	3441	-0.98	1.56	0.50
EVER2B	3647	-0.37	1.12	0.31
EVER3	3347	0.45	0.81	0.22
EVER4	3213	-0.04	1.07	0.20
FROGP	4120	0.70	0.82	0.26
G1166	4339	0.96	0.58	0.30
G1362	4246	0.57	0.90	0.38
G1486	4322	-0.56	1.23	0.30
G1487	4296	0.97	0.76	0.75
G1488	4220	-0.28	1.03	0.22
G3074	4358	0.79	0.07	3.33
G3327	4263	0.96	0.54	0.44
G3328	4225	0.47	0.75	0.22
G3329	4314	0.09	1.01	0.23
G3353	3663	-0.12	1.12	0.12
G3354	3305	0.05	0.90	0.29
G3439	3017	1.04	0.79	0.49
G553	3935	-1.13	1.24	0.68
G613	4314	0.42	0.88	0.35
G614	4247	1.23	0.72	0.79
G789	4162	0.89	0.75	0.33
G852	4178	1.11	0.43	0.64
G855	4162	-0.05	1.02	0.08
G858	3415	0.11	0.94	0.24
G860	4383	-0.22	1.04	0.25
G864	4380	0.32	0.87	0.19
G973	4300	1.14	0.66	0.52
G975	4142	1.31	0.87	1.29
G976	4213	2.16	0.51	1.53
S18	4328	0.59	0.77	0.27
S182	4332	-0.01	0.93	0.38
S196A	4337	0.49	0.92	0.41

Table 6.2.14 Half-Width of 90% Total Uncertainty Band for Canals

Station	Sample Size	a (intercept)	b (slope)	Uncertainty Band
1-8C	4383	1.47	0.91	0.26
C2.74	4122	0.97	0.74	0.69
E3HW	4229	7.76	0.16	0.58
G124HW	540	8.62	0.15	2.15
G211HW	1822	2.14	0.64	0.59
G54HW	4346	3.24	0.18	0.89
G56HW	4383	5.85	0.18	1.52
G57HW	1835	2.32	0.49	0.20
S118HW	4376	-0.24	1.06	0.12
S119HW	4345	-1.14	1.29	0.58
S11AHW	2902	-2.56	1.20	0.52
S123HW	3437	-0.01	0.97	0.18
S13HW	4383	0.96	0.31	0.44
S148HW	4221	2.21	0.45	0.89
S149HW	4334	1.08	0.63	0.43
S155HW	4225	4.40	0.43	0.52
S165HW	4327	1.55	0.56	0.59
S166HW	4383	-0.12	1.14	0.59
S167HW	4383	0.91	0.76	0.35
S176HW	4383	1.75	0.60	0.50
S177HW	4383	1.22	0.65	0.38
S179HW	4378	-0.25	1.11	0.12
S18CHW	4380	0.73	0.68	0.27
S197HW	4233	-0.10	0.93	0.46
S20FHW	3750	0.54	0.62	0.30
S21AHW	4375	0.96	0.49	0.32
S21HW	4383	1.27	0.35	0.37
S22HW	4366	0.36	0.81	0.35
S25HW	3910	0.92	0.48	0.28
S26HW	3755	2.23	0.13	0.62
S27HW	4299	1.33	0.21	0.37
S28HW	4383	1.54	0.15	0.38
S29HW	4283	1.51	0.28	0.41
S30HW	3136	3.36	0.45	1.02
S331HW	4369	2.17	0.52	0.60
S332HW	4383	0.48	0.89	0.21
S333HW	4383	-1.33	1.15	0.33
S334HW	4383	0.20	0.94	0.48
S335HW	4383	-0.13	1.02	0.04

Table 6.2.14 (cont.) Half-Width of 90% Total Uncertainty Band for Canals

Station	Sample Size	a (intercept)	b (slope)	Uncertainty Band
S339HW	4177	2.43	0.78	0.55
S33HW	4383	1.09	0.68	0.23
S340HW	4366	0.60	0.92	0.46
S344HW	354	1.27	0.93	1.12
S36HW	4383	3.80	0.15	0.54
S37AHW	4383	3.77	0.00	0.54
S37BHW	4373	6.02	0.12	0.46
S44HW	4349	5.53	0.21	0.39
S46HW	4363	9.59	0.35	1.38
S9HW	4380	-0.57	1.09	0.59

Table 6.2.15 Half-Width of 90% Total Uncertainty Band for WCAs

Station	Sample Size	a (intercept)	b (slope)	Uncertainty Band
1-7	4124	-1.30	1.07	0.23
1-8T	4028	-0.99	1.08	0.42
1-9	3939	-3.20	1.21	0.35
2A-17	4383	-0.36	1.02	0.18
2A-300	4112	0.79	0.92	0.33
3A-10	3797	1.84	0.84	0.28
3A-11	3785	0.56	0.89	1.36
3A-12	3755	3.11	0.71	0.48
3A-9	4383	1.51	0.84	0.45
3A-NE	4150	4.71	0.55	1.19
3A-NW	3860	2.58	0.77	0.40
3A-S	4285	0.20	0.97	0.19
3A-SW	4131	-1.78	1.18	0.27
3B-2	1604	4.46	0.45	0.66
3B-29	992	4.79	0.40	0.82
3B-3	1571	3.06	0.63	0.43
3B-SE	3003	-0.19	1.08	0.63
G618	4255	1.20	0.83	0.31
L28-2	2194	0.01	0.97	1.81
L29	4383	0.88	0.85	0.40
SHARK	4228	0.24	0.97	0.06
WCA2E4	433	0.08	1.00	0.06
WCA2F1	432	2.13	0.83	0.58
WCA2F4	432	-0.36	1.03	0.08
WCA2U1	433	0.71	0.96	0.35

Both methods are 1st order approximation, which can only give a basic overview of the model uncertainty. A higher order method would be helpful for further study. Also, detailed analysis considering the specific situation of each individual gage would provide insight to the cause of uncertainty and would be beneficial to the overall uncertainty analysis.